detection by a driver while high color difference increases the detection chances. This means that the highly color difference between the sign region (blob) and its surrounding regions, is the better of road sign visibility.

- Surrounding Simplicity

This Parameter measures the amount of details on the surrounding regions. The edges of all surrounding regions are extracted and the number of pixels of these edges is calculated. The ratio between the number of edges pixels in the surrounding regions and the total number of pixels in these regions is used to determine the shape complexity (C) of road sign surroundings. The simplicity parameter (S) is calculated using the complexity ratio as follow:

$$S = 1 - \frac{N_E}{N_T} \quad (5)$$

where N_E is the number of pixels of all edges in the surrounding regions and N_T is the total number of pixels in the surrounding regions.

Simple road sign surrounding environment will yield in a high value for the simplicity parameter and thus; will increase the visibility level. The overall simplicity level of sign surrounding regions would be either high or low depending on the simplicity parameter value.

- Occlusion

This parameter measures the percentage of road sign area occluded partially by trees, leaves, or other objects. Partial occlusion on both top and right side of road sign region is considered while occlusion on both left and bottom side is neglected. The occlusion parameter (O) is defined as:

$$O = 1 - \frac{A_O}{A_T} \quad (6)$$

where A_O is the real filled area (with occlusion) of road sign region (blob) calculated as the number of pixels and A_T is the estimated area of road sign region (blob) without occlusion. Both left and bottom dimensions are used to calculate A_T as shown in Fig.5. The estimated area of road sign (A_T) is calculated using L_3 and L_4 as follow:

$$A_T = L_3 * L_4 \quad (7)$$

Occlusion level can be either low or high depending on the occlusion parameter value. High occlusion of sign region would decrease the detect-ability and visibility of road sign.

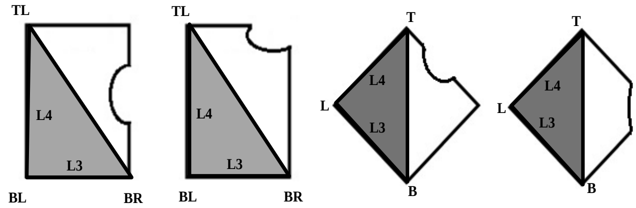

Fig.5. Partially occluded rectangular and diamond sign shapes.

- Tilting

This parameter computes the tilting angle (θ) geometrically using the tangent between the left and bottom points of road sign shape. In [15], we have proposed a framework for tilting angle computation of different sign shapes as shown in Fig.6. The tilting parameter (T) for rectangular signs is defined as:

$$T = \frac{180}{\pi} * \tan^{-1}\left(\frac{|X_B - X_L|}{|Y_B - Y_L|}\right) \quad (8)$$

and for diamond shapes is defined as:

$$T = \frac{180}{\pi} * \tan^{-1}\left(\frac{|X_B - X_L|}{|Y_B - Y_L|}\right) - 45 \quad (9)$$

where X_B and X_L are the x-axis coordinates of both the bottom and left points and Y_B and Y_L are the y-axis coordinates of both the bottom and left points.

Tilting level can be either low or high depending on the tilting angle value. High tilting of road sign would decrease its detect-ability and thus; its visibility level.

3.4 Visibility Level Determination

Road signs are classified subjectively in terms of visibility levels to: low, medium, or high. The four detect-ability parameters: color difference (D), surrounding simplicity (S), occlusion (O), and tilting (T) calculated in the previous stage are used together to decide the visibility level as shown in Table 1.

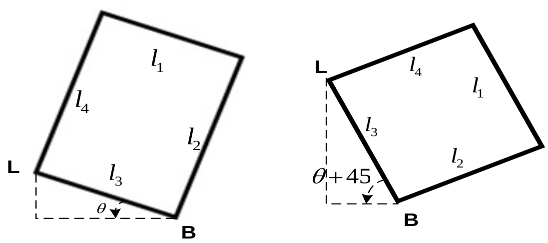

Fig.6. Rectangular and diamond road sign tilt angle.

Table 1: Visibility estimation using detect-ability parameters.

Color Difference (D)	Simplicity (S)	Occlusion (O)	Tilting (T)	Visibility Level (VL)
x	x	high	x	low
low	low	x	x	low
low	high	low	high	medium
high	low	low	high	medium
low	high	low	low	high
high	low	low	low	high
high	high	low	x	high

The four parameters participate in the final decision of road sign visibility level but with different weights. Occlusion parameter is given the greatest weight while tilting has the smallest weight in the decision. Both color difference and surrounding simplicity are equally weighted less than occlusion and higher than tilting.

4 Experimental Results

The proposed visibility estimation system has been applied on road signs in-vehicle images from the United States. These in-vehicle images have been captured using SAMSUNG ST65 camera in addition to images from VISAT™ Mobile Mapping System. Images were scaled to 864x648 pixels and 802x617 pixels by numeric fraction to overcome the impact of objects' distortion. The proposed visibility estimation system has been implemented in MATLAB software running on 2.4-GHz i3 CPU.

A sample of 32 in-vehicle images has been used in the training phase to determine the threshold value of each detect-ability parameter. Another sample of 118 in-vehicle images divided as: 62 rectangular regulatory signs and 56 diamond warning signs has been chosen to verify the effectiveness of the proposed system. Both the training and the testing sample contain a variety of road signs under different visibility situations.

In our proposed system, each road sign should be classified as high, medium, or low in terms of visibility level. The decision of visibility level has been taken according to the four detect-ability parameters as shown previously. Some detect-ability parameters have been computed between the sign region and its four surrounding regions. Fig.7 shows an example of segmenting the four regions of a warning sign.

a b

Fig.7. An example of the segmentation process of the four surrounding regions of a warning sign.

The relation between the four detect-ability parameter values and their levels has been decided using different threshold values as is shown in Table 2. These threshold values have been chosen based on a set of 32 in-vehicle images (training set) divided as: 16 rectangular signs and 16 diamond signs. The decisions of a human expert have been used in this training phase to determine suitable threshold values for the four detect-ability parameters.

Table 2: Relation between visibility parameter values and visibility levels.

	High	Low
Color difference	≥ 120	< 120
Surrounding simplicity	≥ .95	< .95
Occlusion	≥ .15	< .15
Tilting	≥ 15	< 15

The proposed visibility estimation system has been tested on 118 in-vehicle images (62 rectangular signs and 56 diamond signs). The decision of the proposed system has been compared with the human expert decision on each sign separately. Table 3 shows the decisions of the proposed system against the human expert decisions. The comparison shows an agreement of both decisions on 105 road signs with an accuracy of 89% while 13 road signs have been decided differently. These 13 road signs have not decided extremely different between the proposed system and the expert. The difference between the proposed system and the expert decisions was only one visibility level.

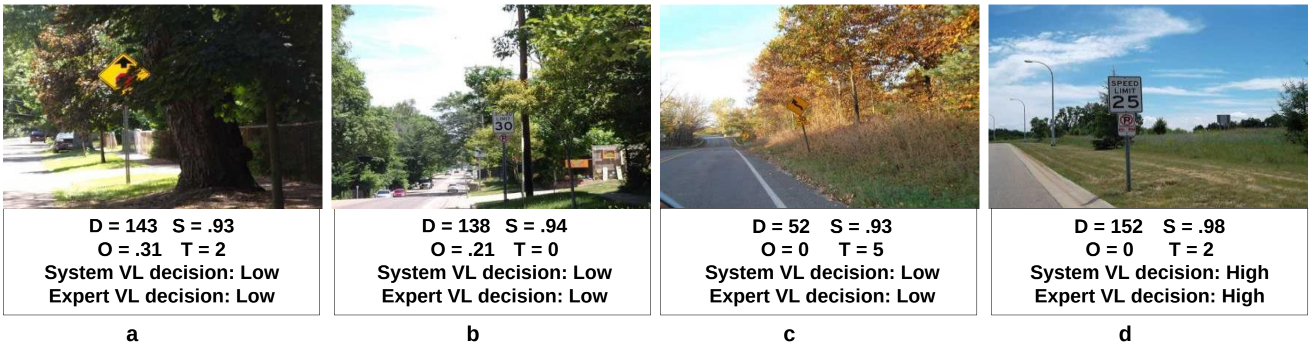

Fig.8. Four in-vehicle images of road signs with detect-ability parameters values, proposed system visibility decision, and expert visibility decision. a) partially occluded warning sign with low visibility level by both the proposed system and the expert. b) partially occluded speed sign with low visibility level by both the proposed system and the expert. c) warning sign in cluttered environment with low visibility level by both the proposed system and the expert. d) speed sign with high visibility level by both the proposed system and the expert.

Table 3 shows that the proposed system has worked better with yellow road signs than white ones. This difference happens because of illumination factor which affects white color (achromatic color) sharply and thus; the color difference detect-ability parameter may not describe the situation accurately.

Finally, it is worth to say that even for cases of disagreement, the decision between the proposed system and the expert does not differ extremely. In ten disagreement cases between the expert and our system, the visibility decision has one level difference. Fig.8 shows examples of visibility estimation of both cases where agreement and disagreement happens between the expert and the proposed system.

Table 3: Comparison between the numbers of road signs decided similarly and differently by the proposed system and the expert.

	Total number	**Number of signs decided similarly**	**Number of signs decided differently**
Regulatory road signs (Rectangular)	62	53	9
Warning road signs (Diamond)	56	52	4

5 Conclusion

In this paper, we have proposed an imaging-based system to estimate the visibility of road signs in the United States. Visibility has been defined as the ability of drivers to detect road signs on roadways (detect-ability). The proposed system can be deployed in Driver Assistance Systems (DAS) as a choosing criterion of what to display to drivers. The proposed system has measured four detect-ability parameters; color difference, surrounding simplicity, occlusion, and tilting to classify road signs with three visibility levels: high, medium, and low.

We are working on improvements such as: 1) applying the proposed system on other sign classes; 2) deploying other visibility parameters that describe the readability of road sign contents; 3) adding temporal weather changes that affect road sign visibility; and 4) considering the effect of the illumination factor on the visibility decision.

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